ultimate constitution of matter,[22] but is firmly grounded upon the cardinal principles of conservation, dissipation and transformation of energy, which have not been invalidated by any single fact of recent science. In the Yale professor's exhaustive memoir on chemical equilibrium we see the huge fabric of theoretical chemistry developed like a plant out of these single germs, and not one of its seven hundred equations and formulæ has been discredited or disproved by any result of laboratory investigation. Rather do the physical chemists tend more and more to look up to Gibbs as the theoretical founder of their science, and each year has brought forth some new and interesting application of his ideas, from the card-diagram by which the engineer tests the heat wastes of an engine up to industries so various as the manufacture and repair of steel rails, the chemical investigation of soils and their constituents, the artificial manufacture of rocks and precious stones, the liquefaction of obstinate gases like helium, the testing of such "materials of engineering" as Portland cement, the complete revision of analytical chemistry and the most recent aspects of colloidal chemistry—the capillary and dispersoid chemistries and the interfacial chemistry (*Oberflächenchemie*) of the Germans. The Gibbs theory of osmosis, in particular, is strong above all others in the simplicity of its ideas, and in stating his theorems that the osmotic pressure and the surface-tension are both of them functions of the temperature and the chemical potentials of the component substances involved, we know that the "chemical potential" of a substance is no mere fanciful concept, but means the measurable surface energy of the substance (per unit mass) that is available for mechanical effect. A substance of higher chemical potentiality than another would therefore be one having a greater surface energy, that is, a greater immediate *intensity* (as distinguished from capacity) for distributing, diffusing or dissipating energy, *i. e.*, for doing work, and such a substance would obviously have a greater power for chemical combination over substances more inert. In connection with the application of his ideas to experimental pathology by Traube and Ascoli, these theorems of a physicist, whom Boltzmann declared the greatest synthetic mathematician since Newton, should have some interest.

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[22] Possibly one reason why some chemists have neglected Gibbs's theory of osmosis is that many years after he published it, he seems to have fallen under the sway of the van't Hoff hypothesis and in 1896 published an independent proof of the latter based upon the assumption that the molecules of the solute "should not be broken up in solution nor united to one another in more complex molecules." (*Nature*, LV., 461.) This *tour de force*, while completely at variance with the chemical hypothesis of the formation of hydrates in solution, does not in the least impair the value of Gibbs's earlier and more comprehensive argument of 1874.

SPECIAL ARTICLES

THE LUMINOSITY OF COMETS

The return of Halley's Comet has given rise to increased interest in these "heavenly wanderers," and it has also induced much speculation as to the cause of their luminosity.

It is known from the revelations of the spectroscope that comets are composed of matter in its various phases. Some comets may be wholly gaseous during most of their journey, but when remote from the sun the gas condenses to liquid and finally freezes, owing to the low temperature of interstellar space.

The spectra of comets change as they pass to and from the sun. Near the sun they show the Fraunhofer lines indicating that the light from them is reflected sunlight. At other times, when nearer the sun, they show emission spectra of sodium, calcium, iron, etc., indicating that the sun's heat has volatilized these metals; but during most of the comet's journey the only light emitted is similar to that produced by the ionization of gases through electric influence.

The nucleus of a comet may be solid, liquid or even more or less dense gas. In any case the nucleus is surrounded by a gaseous envelope which is more attenuated the greater

the distance from the center of gravity of the comet, like the atmosphere surrounding the earth; but much more rarefied than the earth's atmosphere, since the mass of the comet is much less than that of the earth. The composition of the gaseous envelope of different comets varies. Cyanogen, hydrocarbons and other gases have been detected in the few comets which have been examined by modern spectrographs.

A comet, then, is a globule of gas, with a more or less dense nucleus, floating in almost vacuous space. During the greater part of its journey it is between the sun and one or more planets.

It is well known that there are electric discharges constantly passing between the sun and the planets. The difference in potential between the earth and the sun is a billion volts. The sun is positive, while the earth and the other planets are negative. Thus we have in our solar system one large anode and numerous cathodes—great and small. The electrons are expelled in steady streams from the earth and other planets toward the sun with ever-increasing speed, acquiring almost the velocity of light as they near the end of their journey. According to Arrhenius, the sun drains the space surrounding it of all of its free electrons as far out as one sixtieth of the distance of the nearest fixed star. The nearest fixed star (α Centauri) is 4.35 light-years distant from the sun, and one sixtieth of this distance would be about 152 times the mean distance of Neptune from the sun. In the meantime the sun is expelling positively charged atoms—ions—carrying the same amount of charge as the electrons, but of opposite character. These ions are about one thousand times as heavy as the electrons and having the same amount of electric charge, they move at about one thousandth the velocity, which, however, is still prodigious. The velocities of groups of positive ions have been measured by Wein, who found one group to have one one-thousandth the velocity of electrons, another one two-thousandth, and still another one one-millionth of their velocity.

When the electrons approach the sun they discharge the ions and cause condensation of the gases. These condensed particles are then exposed to the radiation of the sun, which, according to Maxwell and Bartoli, is sufficient to balance the weight of a drop 8×10^{-6} cm. in radius, having the density and capacity of water, *i. e.,* a radiation pressure of about 2.5 times solar gravity. Therefore, these particles are expelled from the sun in enormous numbers with great velocity.

Thus we have the comet—a gaseous body with a more or less dense nucleus—a conductor, in a constant electric stream which increases in energy as the comet approaches the sun and diminishes as it recedes. The anode is always the same, but the cathode is changing from time to time as the comet proceeds in its orbit; each cathode and the comet constantly shifting their relative positions.

As the comet approaches the sun it encounters, more and more, the resistance of the positive discharge, and this "ionic breeze" forces the comet's gaseous envelope away from the solar anode. This positive discharge consisting of material one thousand times as heavy as electrons and traveling at a tremendous velocity would afford considerable resistance.

The comet, being between an anode and a cathode, becomes electrically polarized, the portion of the nucleus, or "head," nearest the sun becomes negative and the opposite side, positive, discharging through the gaseous envelope, brushed back more or less by the "ionic breeze" from the sun, toward the strongest cathode. In fact, if there were no brushing back of the gaseous envelope the electrical disturbance would be in the direction of the cathode and the illumination would take place only in the ionized path, thus giving the effect of a "tail" or streamer. The brushing back of the envelope lengthens the streamer, and since the effect of the "ionic breeze" becomes greater as the comet approaches the sun, the streamer therefore becomes progressively longer. As the comet moves toward the sun the "tail" not only becomes longer but brighter, because the increasing heat more and more attenuates the

gaseous envelope by expansion, thus increasing its electrical conductivity; the "ionic breeze" becomes stronger and the electrical energy more intense. Should the comet get in such a position as to be under the influence of two or more planets acting as cathodes at the same time the streamer will spread out or may divide into several "tails" stretching out toward each cathode. The direction of the "tail" will depend not only on the position of the planet acting as the cathode, but it will be modified by the influence of the magnetic field it happens to be passing through at the time.

It is impossible, of course, to exactly reproduce the cometic conditions; but they can be represented fairly well with a glass tube vacuated, containing another glass tube enclosing a highly attenuated gas. When this double tube is brought within the range of an electric disturbance such as Hertzian waves or Tesla oscillations, the inner tube shows the cometic glow. The effect is very well shown if the tube is placed near the secondary of a fair-sized induction coil giving a two- or three-inch spark, the glow having, at the positive end of the inner tube, the appearance of the "head" of a comet. If the direction of the current in the coil is reversed, the "head" in the inner tube will reverse. No terminals are necessary in either tube. Thus the conditions are the same as in interstellar space, except the globule of gas is enclosed in a glass tube and is of uniform density throughout.

The properties of the luminous gas in the tube under the influence of Hertzian waves are the same as those of a gas in an ordinary Plücker tube. The direction of the luminous stream is changed when in a magnetic field perpendicular to the lines of magnetic force. If the cathode end of the tube be from you and the north pole of the magnet on your left, the stream is attracted. When the poles are reversed, it is repelled. Some gases at certain stages of rarefaction show marked stratification and form brilliant nodes when the discharge passes through them. This nodal effect is greatly intensified in a magnetic field, especially if the gas be hydrogen, carbon monoxide or carbon dioxide. By pulling a magnet perpendicular to the direction of the discharge, from one end of the tube to the other, the stream of ions is considerably lengthened, while the magnet makes little progress in pulling the light electrons against the discharge of the heavier ions.

As the comet passes through the varying magnetic fields during its flight, the effect will be manifest in varying the direction, and curvature of the "tail," and in forming nodal effects which have been frequently noticed and described as multiple "heads."

Some observers have announced that the light from certain comets is polarized. Zeeman has shown that light, when it passes through a magnetic field perpendicular to the lines of force, is plane polarized, and if it passes parallel to the lines of force it is partly plane and partly circularly polarized. Therefore it is natural to suppose that cometary light would be polarized in a manner depending on the direction of the magnetic fields through which it passes, and to an extent commensurate with the intensity of these fields.

The color of the light emitted by a comet will depend on the constituents and on the density of its gaseous envelope. The light emitted by a gas in a Plücker tube will change color as the pressure decreases, generally becoming lighter. The brightness diminishes as the voltage decreases. Thus as the comet recedes from the sun all conditions serve to diminish its luminosity, *i. e.*, the gaseous envelope condenses and the electric energy weakens until the comet ceases to emit light.

Halley's comet was reported to have lost its "tail" as it passed the earth last April. This was probably only an apparent loss. When the comet came under the dominating influence of the earth acting as the strongest cathode, the electrified stream was drawn directly toward us and we viewed it "end-on." As the comet passed beyond us the more distant planets became the cathodes and the "tail" reappeared.

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June, 1910